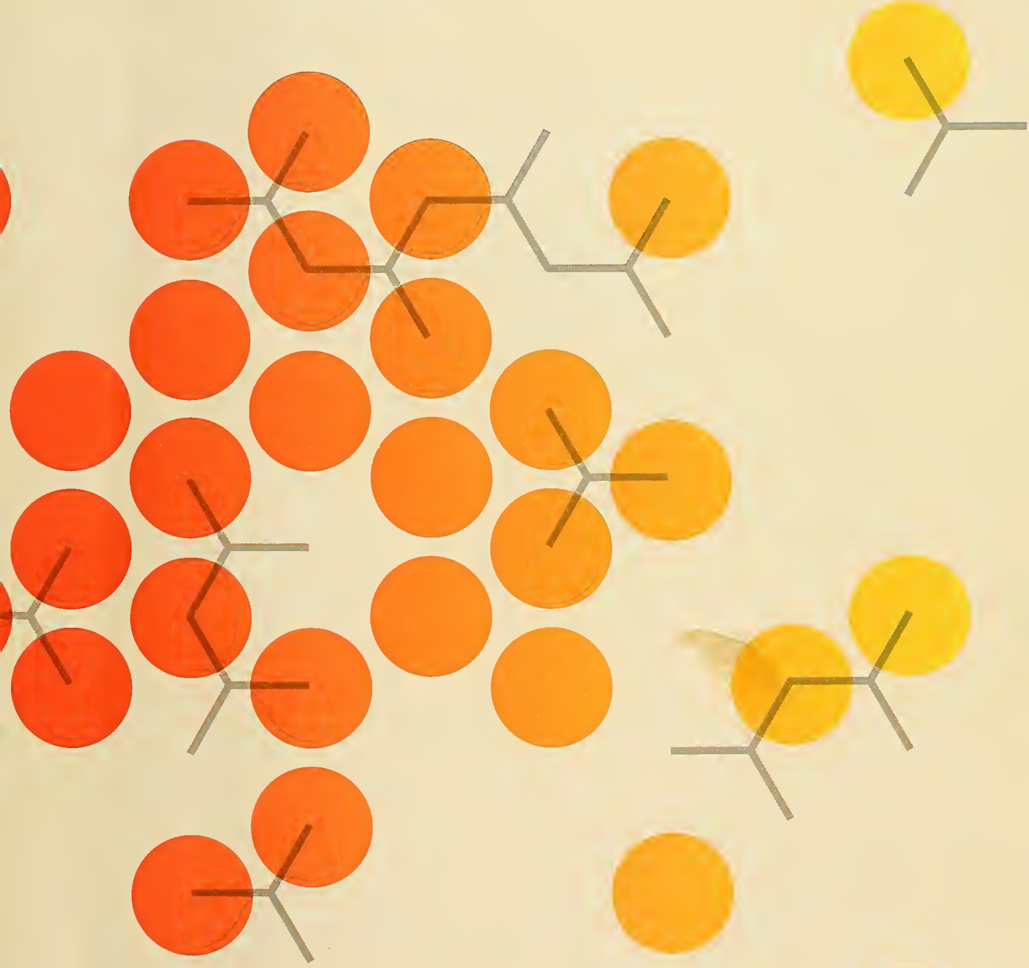
The Consortium of The Center for Complex Systems



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Brandeis University

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THE CONSORTIUM
OF
THE CENTER FOR COMPLEX SYSTEMS

BRANDEIS UNIVERSITY

WINTER, 1990/91

Irwin Levitan, Ph.D., Professor of Biochemistry and Director of Center for Complex Systems

Arthur H. Reis, Jr., Ph.D., Associate Provost and Project Director for Center for Complex Systems

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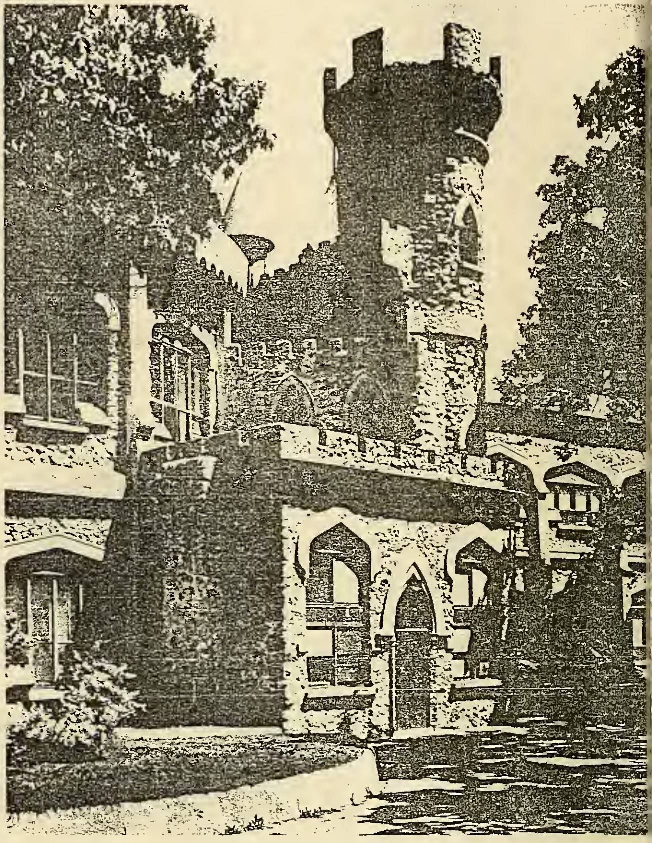
BRANDEIS UNIVERSITY

Of the approximately 2,000 accredited colleges and universities in the nation, Brandeis is one of only 100 recognized as research universities. As such, it enjoys a national and international reputation. In recognition of its standing as a research university, Brandeis recently was elected to membership in the Association of American Universities (AAU), one of the most prestigious associations of 56 major institutions of higher learning. Research and academic programs in the life, physical and mathematical sciences, and those in the social sciences, humanities and fine arts, explore areas of frontier science and technological importance as well as societal and humanistic concerns.



STUDENTS	
Undergraduates	2800
Graduates	800
DEGREE PROGRAMS	
Undergraduates	30
Graduates	20
OPERATING BUDGET	$125 Million
SPONSORED PROGRAMS	$35 Million
FACULTY	374*
SIZE/LOCATION	250 Acres in Waltham, MA 15 Miles West of Boston, MA

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* Including 7 members of the National Academy of Sciences; 2 MacArthur Foundation Prize Winners; and numerous other prestigious awards,fellowships, and scholars.

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THE CENTER FOR COMPLEX SYSTEMS

THE CENTER FOR COMPLEX SYSTEMS
AT
BRANDEIS UNIVERSITY

THE VISION

Combine world class scientists from a wide range of interrelated disciplines in a collegial atmosphere which fosters both independent and cooperative research.

Focus the research on the brain and nervous system - from the molecular and cellular level through the sensory and cognitive level.

Use the knowledge obtained to help:

Prevent or cure diseases related to

- Dementia (e.g. Alzheimer's)
- Sleep disorders
- Motion sickness
- Depression
- Cardiac and Kidney function
- High blood pressure
- Learning, Memory and Retardation
- Nerve cell function and synaptic connections

Tailor Drug Therapies to a Particular Site and Disease

Develop Advanced Computer Concepts Including

- Neural networks
- Parallel processing architectures
- Software development tools

Create Adaptive Planning Mechanisms Which are Useful in a Wide Range of Situations Such As

- Robotics
- Factory automation
- Medical decision making
- Pattern recognition
- Document retrieval

Develop Advanced Information Acquisition, Transmission, Storage and Retrieval Mechanisms

Improve People's Ability to Learn and Remember

TODAY'S REALITY

The Center Faculty presently includes

35 Members* from 7 Disciplines:

- Biology
- Biochemistry
- Chemistry
- Physics
- Computer Science
- Linguistics and Cognitive Science
- Experimental Psychology

Initial funding for the Center's new facility has been received

- Architectural work is underway
- Construction is scheduled to be completed in 1993

Examples of faculty cooperative and independent accomplishments, since the Center's founding in June of 1989, include:

Award of a $1 million grant from NIMH

- This grant supports work of biologists, chemists and physicists who are developing computer models of interactions among nerve cells in neural circuits which control behaviors.

Construction of electronic models of biological neural networks

Development of a new software programming tool for massively parallel machines

Creation of new data compression algorithms and hardware to perform real time, adaptive compression at data rates in excess of 300 megabits per second

Isolation of genes which are:

- Closely related to a gene associated with Alzheimer's disease
- Important for long-term memory

Brief descriptions of some of the scientific work presently underway are presented in the following pages. Appendix A provides a more detailed description of the Center. Appendix B describes the individual departments and the research interests of the faculty members. Appendix C illustrates some of the Center's ongoing scientific programs.

*** The Center faculty includes Howard Hughes Medical Institute Investigators; NIH Merit Award Winners; NIH Jacob Javits Award Winners; DARPA Researchers; Searle, Merck, and Markey Scholars; Guggenheim Fellowship holders; and Fellow of the American Association of Artificial Intelligence.**

REPRESENTATIVE CENTER RESEARCH ACTIVITIES

NEUROBIOLOGY

Subject Area	Potential Application Areas
Ion Channels are being studied to determine how these proteins are able to discriminate between very similar ions (Na^+,K^+) and how they open and close in response to external stimuli. Related work studies the molecular mechanisms which nerve cells use to modulate the activity of individual ion channels. (Levitan, Lisman, Miller)	Understanding and treating high blood pressure, kidney malfunction, arrhythmia, cystic fibrosis, and in general understanding how nerve cells generate electrical signals.
Nerve Cell Growth & Synaptic Connections One of the approaches used in this work includes the isolation and detailed biochemical characterization of novel growth factors which influence neurite regeneration and synaptic strength (Levitan)	Dealing with trauma of the nervous system including reformation of synaptic connections and restoration of function after injury.
Biological Rhythms extending from a gene which can change biological clocks to models and algorithms of behavioral data. (Hall, Rosbash)	Sleep disorders, depression, jet lag, relationship between short period and long period oscillations.
Modulation and Modeling of Biological Networks combines the efforts of chemists, biologists, and physicists. This work involves experimental studies of the biology of neural networks..We are constructing more realistic models of a biological network, the stomatogastric ganglion in lobsters and crabs. Issues we are actively pursuing include the stability of the network (how can it produce a stable pattern over a wide range of frequencies) and modification of the network by neural modulators (how can we distinguish intrinsic cellular changes from alterations in synaptic strengths). This work involves an active interplay between mathematical modelling, computer simulation and biological experimentation. Theoretical constructs are tested using simple neuron systems as the precursor to larger and more complex systems. (Abbott, Epstein, Marder)	Understanding the functioning of the nervous system and longer term, treating disorders of the central nervous system which are associated with rhythmic behaviors, e.g., respiration, locomotion, cardiac rhythms.

Oscillating Chemical Reactions developed using a systematic design algorithm, and often coupled together to produce unusual results, e.g., "oscillator death" or "rhythmogenesis". (Epstein)	Chemical processes for developing advanced materials, e.g., new or improved polymers; tailoring drug administration therapies, e.g., chemotherapy; modeling of biological neural networks.
Molecular and Cellular Basis for Memory and Learning involves theoretical and experimental work on molecular switches as the basis for storing information about synaptic strength. In addition, work is underway on genes involved in learning and memory using techniques such as gene mapping, cloning, and biochemical characterizations of gene products. (Lisman, Tully)	Senile dementia including Alzheimer's disease; Amnesia; Normal memory loss related to aging; Learning disabilities; Computer memory and information storage.
Nervous System Development studies genes which are important for normal development of the brain. This work has uncovered a gene essential to normal brain development which is remarkably similar to the Alzheimer's protein precursor. (White)	Treatment of Alzheimer's and abnormal development of the nervous system, e.g., Down's Syndrome, retardation.
Structure and Function of Cell Surface Receptors studies the mechanisms by which cell surface receptors change external signals into meaningful intracellular biochemical responses. As part of the research, genes for various GTP-binding regulatory proteins (e.g., rhodopsin) have been designed and synthesized and at times reconstituted with chromophores. These "designer genes" are used in site-directed mutagenesis studies to determine receptor characteristics. (Oprian)	Advancements related to Photography; Eye Protection; Infrared and Night Vision; Gene Design and Synthesis. Drugs related to vision and other systems which have similar regulatory proteins.

COMPUTER SCIENCE

Subject Area	Potential Application Areas
Case Based Reasoning in which the system uses a memory of previous plans or routines to act or respond based on the "nearest global match" and then adapts that response or action based on the specific situation at hand. (Alterman, Waltz)	A wide range of AI situations including but not limited to: Robotics; Factory Automation; Medical Decision Making; Visual Object Recognition; Game Playing; Document Retrieval; in general, those areas in which "Adaptive Planning" is beneficial.
Data Compression This research is investigating novel approaches to "lossy" compression and developing massively parallel algorithms capable of high data rates needed for high definition video. In related work a massively parallel custom VLSI chip has been designed for fully adaptive lossless compression at over 300 million bits per second. (Storer)	HDTV; Transmission at very high data rates.
Microanalysis research is underway to obtain precise estimates of the running time of programs in terms of an abstract description of the particular machine on which the program will be executed. Continuing research is developing techniques to analyze the performance of programs executing on sequential and parallel machines and designing practical software tools for program analysis based on these techniques. (Cohen, Hickey)	Software tools to help programmers take advantage of the speed, size and complexity of emerging parallel architectures.
Programming Models and Languages for Massively Parallel Computations This research concentrates on continued development of a new language, Divacon, which makes programming for massively parallel machines simpler and less time consuming. Divacon is designed to use a small set of simple primitives with orthogonal properties and a small set of functional forms which can be used to construct complex forms from simple ones. (Mou)	Develoment of parallel algorithms for scientific and engineering problems; software development tools for parallel programming.

EXPERIMENTAL PSYCHOLOGY

Subject Area	Potential Application Areas
Human Sensory-Motor Adaptation This work is carried out in the unique **Graybiel Spatial Orientation Lab** located on the Brandeis campus and also under parabolic flight conditions. A major area of interest is the way in which human movement control and orientation are calibrated to the normal 1G force environment of Earth. Other areas include adaptation of sensory-motor perception and control (e.g. eye/hand coordination) to non-traditional gravitational and rotating environments. (Lackner)	Understanding and treatment of motion sickness; the effect of aging on balance and motor control; Artificial reality or Telepresence which has important implications for industries as diverse as Entertainment, High Performance Aircraft, Remote Maintenance, Training and Simulation.
Visual Space Perception Work examines the way in which shading, texture, and motion are used to permit perception of 3-dimensional objects and shapes from the 2-dimensional visual information supplied by the eye to the brain. Other work examines the way in which the visual nervous system detects objects that move "in depth". Specialized neural pathways embodied in the brain's architecture are being studied to understand their individual contributions to the process. Still other work examines the impact of the developmental process on visual and sensory perception by working with infants of varying ages. (Halpern, Todd)	Design of machines to control their own behavior. Improvement of visual displays used in man-machine interactions. Toy design. Child development.

LINGUISTICS AND COGNITIVE SCIENCE

Subject Area	Potential Application Areas
Language Acquisition, Representation, and Structure examines the way in which language is acquired at different stages of development recognizing that biological differences between children and adults may strongly influence or control the learning process. In addition, the work explores the way language is represented internally (cognitively) and how this relates to the structure of language, the way words relate to each other, and how they are represented internally. (Grimshaw, Prince)	Speech Recognition; Automated Dictionaries; Teaching; Data Base Development; Text and Information Storage and Retrieval.
Research is also going on in conjunction with Computer Scientists to develop computational models of natural language; and with Experimental Psychologists to determine the macro processing of language in the brain by studying aphasia resulting from local brain damage. (Grimshaw, Pustejovsky)	

THE OPPORTUNITY

Corporations are invited to join **The Consortium of The Center for Complex Systems**, now in formation. Those corporations who are "present at the creation" of The Consortium have an unusual opportunity to

Interact frequently with outstanding scientists working in areas important to

- Pharmaceuticals
- Biotechnology
- Artificial Intelligence
- Computer software and hardware
  - parallel processing
- Vision and image processing
- Learning and Memory
- Language, Data and Information
  - acquisition
  - transmission
  - storage
  - retrieval

Access Research in Progress

- Use this early, first hand knowledge to guide and plan their own individual applied research - within both the **Center** and their own laboratories

* * * * * * * * * * * *

THE PERSONAL TOUCH

The Center has included more relevant disciplines under one umbrella than any other institution attempting to work on the brain and nervous system. However, both the Center and Brandeis University are relatively small compared to the other first rate institutions working in this arena. Thus Consortium members can and will be given personal attention by the outstanding faculty,. . . . . and not relegated to graduate students or administrators. The smaller size and interdisciplinary emphasis also ensures that individual faculty will be aware of and can direct Consortium members to related research being done by other Center faculty.

The Consortium is described in the following pages.

THE CONSORTIUM
OF
THE CENTER FOR COMPLEX SYSTEMS

THE CONSORTIUM
OF
THE CENTER FOR COMPLEX SYSTEMS
AT
BRANDEIS UNIVERSITY

PURPOSE

The Consortium of The Center for Complex Systems at Brandeis University provides the scientists of member companies a highly professional, yet intimate and informal atmosphere in which:

- Center faculty and member company scientists interact in a direct and collegial manner;
- The results of basic and applied research undertaken at the Center are transferred to member companies in an efficient and effective manner; and
- Industry scientists can communicate their needs and concerns to Academia in a way that is conducive to finding solutions.

THE PROGRAM

Semiannual meetings which will include:

- Formal presentations by selected faculty members who will report on their most recent research;
- Informal gatherings of small groups of faculty and consortium members with similar interests (Questions and the exchange of ideas will be encouraged); and
- Informal meetings with individual faculty members.

Access to individual or small groups of faculty members by phone or in person.

Circulation of faculty articles and papers prior to publication.

Technology licensing "right of first refusal":

- **For work sponsored by a Consortium member:**
  First to sponsor;
  Next to other members of Consortium; and
  Then to public at large.
- **For work sponsored by Government agencies:**
  First to Consortium members; and
  Then to public at large.

Space and time permitting, the Center will permit qualified Consortium member scientists to work in faculty laboratories for:

- Training in new techniques, procedures, and equipment;
- Revitalizing scientific staff; and
- Joint research

A special graduate student and post graduate student recruiting program tailored for the Consortium members.

Use of Center faculty as guest lecturers at Consortium member's own facilities.

(The Program, continued . . .)

Preparation and dissemination of regular reports of Center research activities.

Membership comprised of companies:

- Small and large;
- Foreign and domestic; and
- From different industries.

A sliding membership fee based on size.

ADVANTAGES AND BENEFITS OF MEMBERSHIP

MEMBERSHIP IN THE CONSORTIUM PROVIDES:

A WINDOW on world class, leading edge technology

- Augment present R&D efforts;
- Expand knowledge base in areas related to current R&D;
- Keep abreast of activities not being pursued in your lab;
- Help set future directions for your R&D expenditures; and
- Interact with individual faculty members.

A PREFERRED POSITION within The Center

- Increase technology licensing opportunities;
- Target research grants more effectively;
- Use laboratory privileges to train young scientists and revitalize more mature scientists;
- Improve recruiting of talented graduate and post graduate students; and
- Develop consulting relationships with faculty members.

A COLLEGIAL ENVIRONMENT in which large and small companies with similar technical interests can interact beneficially.

Plus (if requested)

- Brandeis library associate membership
- Access to the Hassenfeld Conference Center
- Brandeis Faculty Club membership

APPENDIX A

THE CENTER FOR COMPLEX SYSTEMS
AT
BRANDEIS UNIVERSITY

BRIEF DESCRIPTION

The Center brings together world class* scientists in a multi-disciplinary setting to investigate the biological, chemical, and physical underpinnings of learning, sensory perception, disorders and diseases of that most complex of systems known as the brain and nervous system.

The Center combines the talents of those who work at the molecular, cellular, and simple system level (neurobiologists, biologists, biochemists, chemists) with model builders (computer scientists and physicists) and cognitive scientists (experimental psychologists and linguists). Individually, and in teams (intra and inter disciplinary), they are developing new explanations, analytical techniques, and computational methods for dealing with complex, chaotic, and dynamical systems which may be applicable to a broad spectrum of applications.

This environment has already spawned unique research projects which would barely have been imaginable without the Center umbrella. For example, linguists from the Psychology Department are collaborating with members of the Computer Science Department to model the way in which the brain processes language. Another project has faculty and students from the Biology, Chemistry and Physics Departments working together on computer models of interactions among nerve cells in neural circuits which control behaviors. This project has recently been funded by a $1,000,000 grant from the National Institute of Mental Health; if such an award to three principal investigators from three different academic departments is not unique, it certainly is rare. The results of studies such as these will be of importance to a variety of fields. On the one hand, they will of course advance our understanding of how the brain works; at the same time, better understanding of the biological systems will contribute to the design of faster and more powerful computer systems, another major goal of the Center.

In another interdisciplinary effort, Professors Irving Epstein (Chemistry) and Eve Marder (Biology) have received a $300,000 NSF grant for their work on chemical and neural coupled networks. As their proposal stated, "By studying some relatively complex chemical reactions and a relatively simple neural network, we hope to derive new insights into how the different parts of a network interact to produce rhythmic behavior. Ultimately, we seek to explain how groups of neurons work together to generate and modulate simple rhythmic behaviors such as walking, chewing, or breathing."

Even without formal collaborations such as those described here, proximity and informal interactions alone will profoundly influence the research direction of Center members. There is a synergy resulting simply from the proximity of scientists with diverse perspectives and approaches to a problem, a synergy with important consequences for fundamental research.

The importance of proximity dictates the need for a central facility to house Center faculty and students if the Center is to develop its full potential. This requirement, together with the long-standing need for new space for the Computer Science Department, led the University to seek federal funds for a new science building. A $3,000,000 grant several

years ago from the Department of Energy for planning and architectural studies was supplemented in November, 1990 by a $4,000,000 award for new construction from the General Services Administration. The construction project is scheduled for completion in the fall of 1993.

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[*] The Center faculty includes Howard Hughes Medical Institute Investigators; NIH Merit Award Winners; NIH Jacob Javits Award Winners; DARPA Researchers; Searle, Merck, and Markey Scholars; Guggenheim Fellowship holders; and Fellow of the American Association of Artificial Intelligence.

APPENDIX B

RESEARCH ABSTRACTS

CENTER FOR COMPLEX SYSTEMS
FACULTY

Neurobiology (B1)

Abbott, Laurence F. (Physics)
Epstein, Irving R. (Chemistry)
Gelles, Jeff (Biochemistry)
Hall, Jeff (Biology)
Levitan, Irwin B. (Biochemistry)
Lisman, John (Biology)
Marder, Eve (Biology)
Meyer, Robert B. (Physics)
Miller, Christopher (Biochemistry)
Oprian, Daniel (Biochemistry)
Rosbash, Michael (Biology)
Tully, Tim (Biology)
White, Kalpana (Biology)

Computer Science (B2)

Alterman, Richard
Cohen, Jacques
Hickey, Timothy
Mairson, Harry
Mou, Z. George
Pustejovsky, James
Storer, James
Waltz, David

Experimental Psychology (B3)

Halpern, Lynn
Kramer, Steven
Lackner, James R.
Morant, Ricardo
Sekuler, Robert (Provost)
Todd, James T.
Wingfield, Arthur
Zurif, Edgar

Linguistics and Cognitive Science (B4)

Grimshaw, Jane
Jackendoff, Ray
Maling, Joan
Prince, Alan S.
Yip, Moira

APPENDIX B1

RESEARCH ABSTRACTS

NEUROBIOLOGY

NEUROBIOLOGY

(Researchers: Abbott, Gelles, Epstein, Hall, Levitan, Lisman, Marder, Meyer, Miller, Oprian, Rosbash, Tully, White)

The neurobiology effort at Brandeis ranges from the study of the individual ion channels in nerve cell membranes, through to the cellular and molecular basis of behavior. In addition, we have close ties with our colleagues in experimental and cognitive psychology who study higher functions of brain and mind, and with members of the physics, chemistry and computer science departments who are interested in computer models of neural function.

Ion channel structure and function is the focus of several research groups, since ion channels are responsible for electrical signalling in nerve and muscle cells. Dr. Christopher Miller studies the basic mechanisms of ion channel proteins, and the relationship of structure to function in these molecules. Dr. Irwin Levitan is interested in the molecular mechanisms cells use to regulate the activity of their ion channels. The Miller and Levitan labs are collaborating in an effort to clone ion channels which exhibit particularly interesting structures and regulatory features. Dr. John Lisman examines the light-dependent ion channels in photoreceptors, the nerve cells which are responsible for transducing visual information in the environment into an electrical signal which can be understood by the brain. Dr. Daniel Oprian also studies visual transduction in his experiments on the structure of the photoreceptor visual pigment, rhodopsin.

Dr. Jeffrey Gelles is interested in the movement of organelles from one part of the cell to another via the cytoskeleton. This is particularly important in nerve cells, which must move proteins and vesicular structures very long distances, from cell body to snyaptic terminal, via the process known as axonal transport. Dr. Gelles uses sophisticated biophysical techniques and video-enhanced microscopy to examine transport mechanisms, and the role of kinesin, a protein which is the "molecular motor" driving axonal transport.

Communication between nerve cells via synaptic connections is another area of concentration at Brandeis. Dr. Eve Marder investigates the interactions among a small group of neurons which control a simple behavior in crabs and lobsters. Because only a few nerve cells are involved, the wiring diagram -- the way the cells are connected -- is known. Thus it is possible to study the way the synaptic connections in the network influence the network. The Levitan and Lisman labs also study synaptic connectivity. Dr. Levitan is interested in the mechanisms which contribute to specificity of synapse formation, and in the mechanisms involved in the regulation of synaptic strength. Dr. Lisman studies very long-lasting changes in synaptic strength which accompany learning and memory.

Dr. Tim Tully takes another approach to learning and memory, namely a genetic one. Certain mutations in the fruit fly, Drosophila, lead to changes in behavior. Dr. Tully is investigating the molecular changes which accompany, and may be responsible for, the aberrant behavior. Other members of the neurobiology group also take advantage of the well-understood genetics of Drosophila. Dr. Kalpana White is interested in genes which control development of the nervous system. She has found a gene which participates in normal neuronal development, and which when mutated disrupts development. Interestingly, this gene codes for a protein, whose amino acid sequence is remarkably similar to that of a human brain protein involved in Alzheimer's disease. Understanding the role of the normal protein in development of the Drosophila nervous system thus may contribute to our understanding of the molecular defect in Alzheimer's disease.

Drosophila exhibit an elaborate courtship and mating behavior. Dr. Jeffrey Hall has assembled an array of mutants which are deviant in one or another aspect of this behavior, and is using these mutants to investigate the molecular mechanisms which might be involved. Dr. Hall, in collaboration with Dr. Michael Rosbash, also uses mutants to study the cellular and molecular correlates of circadian rhythms in Drosophila behaviors.

The nervous system produces many rhythms in addition to circadian ones. Dr. Marder is collaborating with Dr. Laurence Abbott and Dr. Irving Epstein to use computer and mathematical models to understand the role of neural oscillators in neural networks.

LAURENCE F. ABBOTT
Professor of Physics

Memory and Learning in Neural Networks

A neural network is constructed from a set of nodes, which may represent individual neurons, that communicate with each other through a complex and highly interconnected network of couplings representing biological synapses. In the simplest models, the nodes are binary on-off devices. Such models can act as associative memories and using methods of statistical mechanics originally developed to treat spin glasses we have learned a great deal about their storage capacities and retrieval properties. In addition, highly efficient learning algorithms have been developed to construct the network couplings needed to solve a specific problem.

For some values of their couplings, neural networks exhibit fascinating oscillatory or chaotic behavior. Oscillatory networks are now a major area of research. To study chaotic behavior, Professor of Physics Robert Meyer and I have constructed an electronic circuit network with fully programmable synapses. The network circuit allows us to begin to relate overall network behavior to general properties of network couplings, a very interesting but difficult problem. We have also constructed an electronic circuit which duplicates some of the behavior of the stomatogastric ganglion and gives us a quick way to explore what happens when modifications are made to its synaptic strengths.

IRVING R. EPSTEIN
Helena Rubinstein Professor
of Chemistry

Oscillating Chemical Reactions

Research in our group covers a number of areas, including oscillatory chemical reactions, dynamical systems, neurobiology and mathematical modeling of ligand-lattice interactions in chemistry and biochemistry.

Many phenomena in living systems involve periodic changes in an organ or set of organs ("biological clocks"). In the past decade, oscillating chemical reactions have blossomed to a major and potentially very important area of scientific research. In our laboratory, we have been studying these systems both experimentally and theoretically, from several points of view. We have achieved the first successful design of a new chemical oscillator - the chlorite-iodate-arsenite system. We have used our systematic design algorithm to expand the family of chemical oscillators from two accidentally discovered reactions to some two dozen deliberately constructed systems. While we continue the search for new types of oscillators, we probe by a variety of techniques, including spectrophotometry, potentiometry, rapid mixing and computer simulation, the mechanisms of those that have already been discovered.

Chemical oscillators can be "tweaked" to give a variety of related phenomena, some with suggestive connections to biological systems. Some of these phenomena under study in our laboratories include spatial pattern formation, in which an initially homogeneous medium spontaneously gives rise to concentric ring or spiral color patterns resembling those seen in the aggregation of slime molds, and chemical chaos, in which concentrations oscillate deterministically, but in an aperiodic and apparently irreproducible fashion that depends very sensitively on the initial conditions.

We have been very interested in the phenomena that can occur when two or more oscillators are coupled together, either physically, i.e., by diffusion or an electrical connection, or chemically, by having two oscillators share a common chemical species. Such systems can give rise to surprising phenomena, such as "oscillator death," the cessation of oscillation in two oscillating systems if the coupling between them has an appropriate value, or the converse, "rhythmogenesis," in which coupling two systems at steady state causes them to start oscillating. Coupled chemical oscillators provide simple models for networks of oscillatory neurons. In many respects, chemical coupling resembles the synaptic connections in neural networks, while physical coupling is analogous to electrotonic (gap junction) connections. We have begun to apply some of the insights gained in our studies of coupled chemical oscillators to the modeling of small neural networks in collaboration with the Marder laboratory.

JEFF GELLES
Markey Assistant Professor
of Biochemistry

Microtubule-Based Mechanoenzymes

My laboratory is exploring the biochemistry and molecular mechanics of kinesin and cytoplasmic dynein, the enzymes that drive rapid transport of materials along neuronal axons. Rapid axonal transport is required for neuronal viability, for regulation and targeting within the developing nervous system, and for the formation and maintenance of the neuromuscular junction. It is an essential link in the pathway by which target cells can influence protein expression in the neuronal cell body and induce synapse formation or maintenance.

Fast axonal transport occurs by the movement of small subcellular organelles along axonal microtubules. Kinesin and cytoplasmic dynein drive this movement using free energy produced by the hydrolysis of ATP. A major goal of the laboratory is to understand the mechanism of enzyme movement along the microtubule and the way that steps in this mechanism are coupled to the chemical reactions of ATP hydrolysis at the enzyme active sites. We study the enzyme-driven movements _in vitro_, using a light microscope assay in which enzyme molecules tagged with microscopic polystyrene beads move along microtubules affixed to a glass surface. Using a digital image processing technique, we can measure the bead movements with a precision (5 Å at 30 Hz) sufficient to study the fundamental molecular events in enzyme movement. Our experiments have demonstrated that kinesin and cytoplasmic dynein interact with the microtubule lattice in distinctly different ways which imply fundamentally different mechanical mechanisms for the two enzymes. We plan to continue studies of the mechanical processes that drive movement of these enzymes and of the chemical reactions to which these processes are coupled.

JEFFREY C. HALL
Professor of Biology

Drosophila Neurogenetics and Molecular Ethology

We work on the function of the nervous system in **Drosophila**. Many of our approaches involve genetic studies of behavior, augmented in recent years by molecular manipulations of genes defined by certain behavioral mutations.

These investigations are in two areas:

A. Neurogenetics of biological rhythms

We have been characterizing and manipulating the **per** gene molecularly, in collaboration with Michael Rosbash and colleagues at Brandeis University. These investigations have involved:

(1) determination of the "clock gene's" informational content; (2) assessment of **per's** expression patterns, at different stages of the life cycle and in a variety of neural and non-neural tissues; (3) comparison of the structure and function of **per** genes in closely vs. distantly related **Drosophila** species; these data have revealed, in part, that certain coding regions are highly conserved and others very diverged, among the different species; such findings have led to interspecific transfer experiments, in which the effects of all or part of a donor species' **per** gene is bioassayed in **D. melanogaster** hosts; (4) considering some broader implications of the phenomena and materials just listed. This has led to some farther out interspecific investigations. For example, an antibody against **D. melanogaster's per** protein was generated using a synthetic peptide portion of the gene. This antibody has been found to mediate staining of known circadian pacemaker neurons in a variety of organisms--ranging from other arthropods, to molluscs, to mammals. These results imply that **per**-like genes may influence rhythms in a wide range of animals. Certain such pacemaker cells (i.e., in the organisms where they are relatively large and accessible) could have the **per**-related proteins within them manipulated qualitatively or quantitatively. Experiments of this kind may permit neurophysiological questions to be asked about the molecular underpinnings of circadian pacemaker functions.

B. Neurogenetics of courtship

How is **Drosophila's** central nervous system programmed to control elements of the flies' reproductive behaviors? We are currently focusing most of our attention on courtship mutants. One is defined by genetic changes at the **fruitless** locus, which cause males not to mate with females and anomalously to court other males. We hope to unravel some of the relevant behavioral and genetic complexities by virtue of the fact that the **fru** gene is approachable molecularly.

Two other courtship mutants were isolated because of abnormal male "singing" behavior: **cacophony** or **dissonance** males generate aberrant sounds from the wing vibrations they direct at females. To approach an understanding of how these species-specific courtship songs are programmed into the fly, we are carrying out high resolution analyses of mutant vs. normal sounds. These tests involve treatments of the digitized song records with spectral- and Neural Network-based algorithms.

The **cac** and **diss** mutations may define genes whose influences on neural functions are versatile, because each of these two mutations interacts with nearby genetic variants causing defects in the flies' responses to light. These issues are being looked into molecularly as well as genetically and phenotypically. The diss gene has been cloned, by virtue of its extreme proximity or identity to one of these "visual system genes." We (at Brandeis) are now analyzing diss's expression and what it encodes. DNA which is very near or at the **cac** locus is also in hand, suggesting that it too can be defined molecularly as well.

The rate at which **Drosophila** males generate the "tone pulse" components of their courtship song varies rhythmically. The cycle durations are short, ranging from about a half-minute to a minute-and-a-half, depending on the species. In one of these, **D. melanogaster**, circadian rhythm mutations at the **period** locus cause song rhythm phenotypes. These song findings provided entres into our more extensive studies of biological rhythms.

IRWIN B. LEVITAN
Professor of Biochemistry
Director, Center for
Complex Systems

Regulation of Nerve Cell Activity

My laboratory is studying the long term regulation of neuronal activity. We are interested in the molecular mechanisms which nerve cells use to modulate the activity of individual ion channels, since these mechanisms must contribute to the neuronal changes which underly such phenomena as learning and memory. The essence of our apporach is a combination of biochemistry and electrophysiology, at the level of individual identified neurons and individual ion channels. One aspect of our recent work has focused on the possibility that the activity of ion channels may be regulated by protein phosphorylation. Ongoing projects include the examination of the effects of purified kinases and phosphatases on the activity of individual ion channels, measured either in isolated "patches" of membrane or following their reconstitution into artificial phospholipid membranes. Attempts to isolate and clone ion channels which are regulatable by protein phosphorylation are under way.

Another approach in my laboratory uses techniques to maintain molluscan neurons in primary cell culture. We are using such cultured neurons in the studies described above, as well as to investigate aspects of neurite regeneration and specificity of synapse formation under defined conditions. This approach includes the isolation and detailed biochemical characterization of novel growth factors which influence neurite regeneration and synaptic efficacy.

JOHN LISMAN
Professor of Biology

Amplification and Switching in Signal Transduction and Memory

We study the process by which light leads to the generation of receptor potentials in photoreceptors. The chemistry of the light-absorbing molecule, rhodopsin, is well understood, but what rhodopsin does to cause a change in membrane conductance is less clear. In my laboratory we have attacked this problem at several levels. We have used the patch-clamp technique to demonstrate that in Limulus photoreceptors, light activates ionic channels having a unit conductance of 40 pS. Since a single photon can produce a conductance-change of ≈10,000 pS, phototransduction must involve enormous amplification involving the coordinated opening of thousands of channels. The chemical basis of this amplification is a topic of major interest in the lab. Recently we have obtained both biochemical and physiological evidence that cGMP is involved in the chemical cascade that gives rise to amplification. We are now trying to further test the role of cGMP and to determine the enzymatic changes that produce the light-dependent increase in cGMP concentration.

A second interest of the laboratory is the property of molecular switches. One important property of such switches is their spontaneous on-off transitions. These must occur because of the finite energy difference between the states. Photoreceptors provide a unique preparation for studying switching because the chemical amplification triggered by early stages in the transduction process makes it possible to detect spontaneous switching of single enzyme molecules. A different property of switches is their long-term stability, especially their ability to store information. We have published theoretical work showing how the Ca/calmodulin kinase, the principal component of the postsynaptic density, could store information about synaptic strength. This storage could be the molecular basis for neuronal memory. We are currently trying to experimentally test the involvement of this kinase in the long-term potentiation of synapses.

EVE MARDER
Professor of Biology

Modulation of Neural Networks

Central pattern generators are groups of neurons found in vertebrate and invertebrate nervous systems responsible for the generation of specific rhythmic behaviors such as walking, swimming, breathing, etc. We are currently studying the mechanisms by which neurotransmitters and peptides modulate the output of central pattern generators.

The central pattern generators we study are found in the stomatogastric ganglion of lobsters and crabs. This is an attractive preparation because of the limited number of neurons (30), the large size of the neurons, the ease of making electrophysiological recordings, and because when the stomatogastric ganglion is removed from the animal, it continues to produce rhythmic motor outputs.

We are using immuno-histochemical techniques to study the distribution of neuropeptides in the neural inputs to the stomatogastric system. We are using electrophysiological techniques to study the action of neuropeptides on the individual neurons of the pyloric system, on the synaptic connections among these neurons, and on the motor output. We hope to eventually explain the mechanisms by which a number of different neurotransmitters and peptides can modify in different ways the neural output produced by the same neural circuit.

A new and important focus of my laboratory is the collaboration with L. Abbott in Physics and I. Epstein in Chemistry to develop a series of theoretical models of the ways in which this neural network generates behaviors. From this work we are obtaining general principles of how networks containing neural oscillators work.

ROBERT B. MEYER
Professor of Physics

Complex Fluids

Complex Fluids are systems that are generally intermediate in their degree of internal ordering, between liquid and crystal states. Examples include liquid crystals, colloidal suspensions, and solutions of polymers or molecular aggregates. These systems are studied by optical microscopy, light scattering, x-ray diffraction, electron microscopy, and by examining their response tc applied external forces, including those due to electric and magnetic fields, and forces producing flow. There are two general motivations of the research: First, these systems exhibit fascinating phenomena at the macroscopic level, many of them quite complex. We observe and experiment with these effects, and try to explain them. Second, we try to understand the macroscopic properties of these systems in terms of their microscopic structure, including both the fundamental properties of their constituent molecules or particles, and the way those particles interact and order. In many cases, this leads to the design of new molecules, or new ways of controlling the ordering, and the production and control of new macroscopic phenomena.

There are several examples of this general approach. First, we study solutions of rigid polymer molecules or rod-like Tobacco Mosaic Virus (TMV) particles which form liquid crystals. These liquid crystals can be very anisotropic in their elastic and viscous properties, resulting in a number of surprising responses to external fields. We study these with video microscopy and computerized image analysis. To understand the macroscopic properties of these systems, we study how the rigid polymer molecules interact with one another and align, using x-ray diffraction. In the case of TMV, we have observed several liquid crystal phases, measured their properties, and made theoretical models to explain the existence of the phases and their properties. We are now undertaking studies of solutions of molecular aggregates. In this case, small rigid molecules aggregate to form long rod-like particles which then order as liquid crystals. Here we want to understand the system at three levels: why the molecules aggregate, how the aggregates order, and the properties of the resulting liquid crystals.

Dynamical Systems

Many of the complex fluids we study exhibit non-linear response to applied forces. Understanding this response is a major research topic connected to similar phenomenology in many fields of physics. We study the properties of non-linear waves, or solitons, in liquid crystals, along with more complex pattern forming responses. We are now undertaking studies of other dynamical systems, such as coupled nonlinear amplifiers and oscillators which may serve as models for small biological neural networks, and simple nonlinear mechanical systems like dripping water, in which each drip that suddenly falls may affect the formation of the next drip at the same location, or the response of drips nearby. These systems can produce so-called deterministic chaos, a kind of non-periodic, almost unpredictable response, which may again be important in many biological systems.

CHRISTOPHER MILLER
Professor of Biochemistry
and Howard Hughes Medical
Institute Investigator

Mechanisms of Operation of Ion Channel Proteins

Our laboratory is investigating the basic mechanisms of operation of ion channels, a ubiquitous class of pore-forming membrane proteins which underlie the generation of electrical impulses in nerve and muscle cells. We would like to know, at the molecular level, how these proteins are able to discriminate among very similar ions, such as Na^+ and K^+, and how they rapidly open and close in response to external signals. We use several approaches towards this end. First, we study the functional behavior of ion channels by reconstituting single channel molecules in "artificial" lipid bilayers and observing these single-channel ionic currents at high resolution. This approach, which combines the chemical simplicity of a reconstituted membrane with the power of single-channel analysis, is being used to deduce the physical dimensions of the conduction pores of several K^+ channels, as well as the disposition of surface charge on the Na^+ channel protein. Second, we are attempting, through protein reconstitution methods, to purify several voltage-dependent ion channels, as a first step towards a detailed molecular analysis: a Cl^- channel from the electric ray *Torpedo californica*, and a Ca^{2+} -activated K^+ channel from skeletal muscle. Third, we have recently begun a project to discover the mechanism of the specific inhibition of K^+ channels by charybdotoxin, a minor protein from scorpion venom; we have synthesized the gene for charybdotoxin, and are now seeking a suitable high-level expression system with which to carry out site-directed mutagenesis and crystallization studies. Finally, we are using site-directed mutagenesis to carry out a detailed molecular and biophysical investigation of a K channel protein of very low molecular weight (~15kDa), via the expression of a fully synthetic gene for the channel.

DANIEL OPRIAN
Assistant Professor of
Biochemistry

Structure-Function Studies of Cell Surface Receptors

The goal of our laboratory is to elucidate the mechanisms by which cell surface receptors transduce extracellular signals into meaningful intracellular biochemical responses. We study a family of homologous sensory and neurotransmitter receptors that function through the intermediary action of GTP-binding regulatory proteins. Members of this family include rhodopsin (the visual pigment of retinal rod photoreceptor cells), cerebral and cardiac muscarinic acetylcholine receptors, and alpha- and beta-receptors for adrenergic agonists.

Our primary interest is to define structural domains that are responsible for the various functions and specificities of these receptors. Our approach is to use site-directed mutagenesis to modify the receptors, and then to characterize the modified proteins in vitro in reconstituted enzyme systems containing purified components. To facilitate this work, we have designed and chemically synthesized a gene for bovine rhodopsin that was tailored for use with site-directed mutagenesis. We have expressed this gene to high levels in monkey kidney cells in culture, reconstituted the protein with 11-cis-retinal chromophore, and purified it to homogeneity using an immunoaffinity procedure. The purified protein has a visible absorption spectrum, and specific activity for light-activation of the GTP-binding regulatory protein "transducin," that are indistinguishable from the pigment isolated from bovine retina. More recently, we have designed and chemically synthesized genes for beta-adrenergic and muscarinic acetylcholine receptors.

MICHAEL ROSBASH
Professor of Biology
and Howard Hughes Medical
Institute Investigator

My laboratory is divided in two halves. The "RNA" half is interested in basic problems that revolve around post transcriptional regulation. We are principally interested in splicing and in RNA transport from nucleus to cytoplasm. Most of our efforts have been directed at addressing these issues in the budding yeast, **Saccharomyces cerevisiae**, an organism amenable to both genetic and molecular genetic attack. We approach these problems both **in vivo** and **in vitro** and are interested in understanding these problems biochemically and physiologically. That is, we want to understand the biochemical mechanisms that underlie splicing and RNA transport as well as how these processes operate in vivo, how they interface with the cell. More specifically, we have been addressing the role of snRNPs (small ribonucleoprotein particles) and in particular the role of U1 snRNP in these processes. Our current working hypothesis is that U1 snRNP plays a prominent early role in intron recognition and in commitment of the pre-mRNA to the splicing pathway (spliceosome assembly). Nuclear retention of pre-mRNA transcripts occurs as a consequence of this commitment step; transport from the nucleus to the cytoplasm is currently viewed as a default step and occurs whenever a nuclear retention signal is not present on a transcript. These early steps in spliceosome assembly, as well as the transport process, are being addressed by searching for and analyzing mutants that are defective in one or both steps.

The other half of the lab is interested in the biochemical mechanisms that underlie biological rhythms. This work is a collaborative venture with Jeff Hall's lab. To gain access to the gene products involved in generating these behaviors, our approach has been to utilize mutants of _Drosophila_ that manifest aberrant rhythms. Although we are interested in several genes potentially involved in the circadian rhythms of _Drosophila_, our studies to date have focused on the _period_ gene because of the extensive genetic work that implicates this gene and its products in oscillator function. Recent results indicate that the _period_ gene products themselves undergo circadian fluctuations _in vivo_, suggesting that a feedback loop exists in which the per products affect their own levels. In very general terms, our work is very broad in scope and involves behavioral analyses, cloning, biochemical purification, _in vitro_ systems, etc. Our long term goal is to understand the biochemical machinery responsible for the major circadian oscillators in eukaryotes.

TIM TULLY
Assistant Professor of Biology

Genetics of Learning and Memory

Work in my laboratory concerns the biological bases of learning and memory. In Drosophila, we can tackle the problem on behavioral, genetic and molecular levels. Our strategy is to create strains of flies, each carrying a single-gene mutation induced by chemical mutagens or by hybrid dysgenesis. Then, flies from each of these mutant strains are trained, in Pavlovian fashion, to avoid a specific odor by shocking them in the presence of that odor. After training, conditioned odor avoidance responses are monitored either immediately to detect defects in associative learning or minutes to hours later to detect memory deficits.

Several X-linked learning/ memory mutants already exist, and biochemical deficiencies have been identified for two of them. The _dunce_ and _rutabaga_ mutations affect specific enzymatic forms of phosphodiesterase and adenylate cyclase -- both of which are components of the cyclic AMP cell-signaling pathway.

These initial results are encouraging but are far from complete. Importantly, we know that the existing mutants do not affect directly the formation of permanent, long-term memory. Our research objective is to better understand this process of memory formation. To this end, we are working on the problem at three levels of analysis: (1) _Behavioral_. Many subtle aspects of behavior can provide valuable information about the formation of long-term memory. Recently, we have developed training procedures in adults that produce memory lasting one week and in larvae that produce memory lasting through metamorphosis. Each procedure can be used to screen for mutations affecting different aspects of memory formation. (2) _Genetic_. We are generating new, transposon-tagged mutations that affect learning or memory. Once a mutant strain is identified, the behavioral abnormalities are characterized, and the gene is mapped. (3) _Molecular_. Creating mutations with transposon tags greatly expedites cloning of the disrupted gene. Accordingly, we have begun cloning one of our new memory mutants. We also are cloning an extant memory mutant, _amnesiac_, which shows normal long-term memory formation but abnormal memory retention shortly after training.

This molecular-genetic strategy will enable us to identify many of the protein components involved with memory formation from early, labile phases to later, stable ones. With these molecular pieces of the puzzle "on the table," we will be able to begin detailed biochemical analyses of learning and memory in normal flies (and humans?). This research ultimately may lead to pharmacological intervention and gene therapy for learning and memory deficits associated with developmental disabilities and ageing.

KALPANA WHITE
Professor of Biology

Neural Development

Research in my laboaratory focuses on neural development. One area involves molecular-genetic studies of gene functions important in early neurogenesis during neuronal maturation. The other area involves study of development and function of specific transmitter/modulator neuronal subsets. We have chosen to use the fruit fly, Drosophila melanogaster, as our model system because of the wealth of genetic and molecular approaches possible in this organism.

The specific genes we study are Appl (β amyloid protein precursor like), elav (embryonic lethal, abnormal visual system), vnd (ventral nervous system condensation defective) and ewg (erect wing). Gene Appl encoded protein resembles the human βamyloid protein precursor which is associated with Alzheimer's disease and thus provides a good model system to study the function of this protein. The genetic and developmental analysis of the loci elav, vnd and ewg have demonstrated that each locus provides a vital function which is important in the formation of the nervous system. Recent molecular data on these genes further demonstrates that these functions are specifically required in the embryonic nervous system. Current research is focused on understanding the function of protein products encoded by these genes and understanding transcriptional control of these genes.

The other part of our program involves the analyses of development of biogenic amine neuron family and their overall role in neural development and function. We are using genetic, molecular, immunohistochemical, and neuroanatomical approaches to specifically manipulate neurotransmitter metabolism and analyze its consequences on chemical organization of the brain neurons.

APPENDIX B2

RESEARCH ABSTRACTS

COMPUTER SCIENCE

COMPUTER SCIENCE

(Researchers: Alterman, Cohen, Hickey, Mairson, Mou, Pustejovsky, Storer, Waltz)

Research in Computer Science at Brandeis covers a broad range of topics, but is concentrated in four areas: 1) artificial intelligence; 2) languages, especially logic programming languages; 3) data and image compression; 4) and parallel computing, which cuts across the other three areas.

Within artificial intelligence, Drs. David Waltz, Richard Alterman and James Pustejovsky direct efforts on case-based and memory-based reasoning; adaptive planning and reasoning, learning, foundations of natural language, and connectionist (or "neural net") models for computation. They have collaborated on a number of projects.

Dr. David Waltz specializes in massively parallel and connectionist models of computation. Connectionist models use large numbers of relatively simple, richly interconnected computational units to model cognitive phenomena. Dr. Waltz has specifically investigated such systems for learning, natural language processing, and classification systems. At the practical end of the spectrum, he has been investigating memory-based reasoning applications built on the idea of global nearest match of an item in associative memory, a powerful but inexpensive operation on new generation massively parallel machines. This class of methods has been applied to tasks ranging from classification of census data to software system troubleshooting. Dr. Waltz is engaged in specific projects applying these ideas to document retrieval and extraction of knowledge from text.

Dr. Richard Alterman has been engaged in research on adaptive planning and natural language processing, especially for stories and for language describing perceptual phenomena. An adaptive planner retrieves memories of previous plans (routines) that seem to match the situation-at-hand. It then adapts that plan (improvises), to match the interpretation it constructs of the situation. Professor Alterman's text understanding work emphasizes "concept coherence", the use of representations that tie together the words, concepts, or discourse units of the text. Event connectivity graphs have been used to generate inferences about text, and to generate summaries of texts. In his current effort, Dr. Alterman has combined adaptive planning, text understanding, and learning research to build a system that can learn to use a novel mechanism (such as an airphone) based on previous knowledge (e.g. a regular pay phone) and commonsense reasoning.

Dr. James Pustejovsky's major goals are to advance our understanding of the semantics of natural language, specifically, word meaning, compositionality, and the global organization of conceptual knowledge as shaped by language; and to verify and test these theories through computational models of representation of text and discourse. Dr. Pustejovsky is applying this research to the important task of automatically extracting and representing facts from very large text databases. He also has pioneered research on "lexical semantics", which he has used for generating machine-usable databases from on-line dictionaries.

Drs. Jacques Cohen, Timothy Hickey,

Harry Mairson and George Mou all specialize on aspects of programming languages. Drs. Cohen and Hickey collaborate on microanalysis of programs, and on logic programming. The objective of microanalysis is to obtain precise estimates of the running time of programs in terms of an abstract description of the particular machine on which the program will be executed. The goals of Drs. Cohen and Hickey's research are to develop techniques and use these to design practical software tools for microanalysis on both serial and parallel machines; this will help programmers realize the promise offered by the exponential growth in the speed, size, and complexity of emerging parallel computer architectures. Drs. Cohen and Hickey also collaborate in research on logic programming, an evolving paradigm for computation based on mathematical logic. A primary goal is to develop very high level languages; this will allow very concise programs that have a greater likelihood of being correct or whose errors can be readily detected. Special attention has been focused on Constraint Logic Programming (CLP) in which problems are stated by simply specifying the problem constraints that should be satisfied.

Dr. Harry Mairson conducts research on the use of data types in programming languages, and the relationship between data types to classical ideas in mathematical logic, with practical applications appearing in the design of programming languages and compilers. The problem of automatically inferring data types in "functional" programming languages has a strong connection with issues in mathematical logic, especially to "constructive intuitionistic logic". Dr. Mairson is working to characterize the computational complexity of theorem proving in various logics associated with respective typing systems.

Dr. George Mou's current interest is to develop a parallel programming language called Divacon, based on a formal model for massively parallel computers by "divide-and-conquer" methods. (Since these parallel computers have departed from the traditional "von Neumann machine" model, much of our past experience with conventional computers cannot be used to guide the practice in the parallel world.) Divacon emphasizes a small set of simple primitives with orthogonal properties and a small set of functional forms that can be used to construct complex functions from simple ones, hierarchically. A preliminary version of the language has been implemented and users have confirmed its expressiveness, modularity, and efficiency.

Dr. James Storer's research covers several areas. In addition to continuing past work on lossless data compression (where the decompressed data must be identical to the original), Dr. Storer directs research on lossy compression (where decompressed data need only be an acceptable approximation to the original such as a digitized image that "looks" as good as the original). His effort includes both theoretical papers and experimental software, concentrating on massively parallel algorithms and custom VLSI chips capable of the high data rates needed for high definition video (over 1 billion bits per second). Some of this work is in collaboration with M. Cohn. Other related research has investigated communications protocols and error correction. Finally, Dr. Storer has been involved in a new effort in collaboration with the AI researchers in the department to build an experimental six-legged walking robot that will be used to test practical motion planning, control, and learning algorithms.

RICHARD ALTERMAN
Assistant Professor of
Computer Science

Adaptive Planning

There were two key features of early models of planning in artificial intelligence. The first was that the planner did not have a memory of previous planning episodes. This meant that the planner was always planning from scratch, constructing a plan out of a small set of operators. The second critical feature was that these early models of planning almost entirely separated the planning and acting phases. For example, a robot given some task would construct a plan from scratch to achieve that task and then in a second phase it would turn the plan over to an execution monitor that would essentially supervise the robot as it went through the steps of the plan. This model of planning and acting proved undesirable because, in general, it failed to provide a model that could deal with various kinds of contingencies that might arise.

My work on adaptive planning was one of the early efforts to deal with the problems of traditional models of planning. An adaptive planner is a commonsense planner. It has a memory of previous plans (routines) and essentially plans, by retrieving a plan from memory that seems to match the situation-at-hand. It then adapts that plan (improvises), during the period of engagement, as a function of the interpretation it constructs of the situation. For example, the first time I ride the Paris Metro, I do not plan from scratch, rather, I retrieve from memory my routine for riding the MBTA and use that as a basis for constructing an interpretation of the actions I should take at the Paris Metro.

Concept Coherence

The notion of coherence emphasizes the connectivity of items in the understanding/ representation. Coherence representations either tie together the words of the text, the discourse units of the text, or the concepts the text invokes. In the theory of event concept coherence (ECC) a sequence of events is represented by a copy of a portion of the web of concepts that holds the events together in semantic memory. The output derived from a ECC analysis is referred to as an event connectivity graph.

The focus of recent work is on the semantics of the concept coherence derived representation scheme. A program called SSS exploits the event connectivity graph in support of several reasoning tasks: SSS uses the graph to identify the conceptual roots of the narrative. An interesting property of the conceptual roots is that they are the minimum set that covers the entire interpretation graph. With the addition of the techniques that determine the conceptual roots, SSS is able to succinctly explain the connection between any two concept coherent events in the narrative. Also implemented in SSS is a measure of importance that quantifies the author's conceptual emphasis. Lastly, SSS combines evidence from the event connectivity graph, the conceptual root analysis, and the importance measure, to generate a description of the basic event content of the narrative.

JACQUES COHEN
Zayre/Feldberg Professor
of Computer Science

AND

TIMOTHY HICKEY
Assistant Professor of
Computer Science

Microanalysis

The objective of microanalysis is to obtain precise estimates of the running time of programs in terms of an abstract description of the particular machine on which the program will be executed.

In microanalysis, we avoid using a single machine language by expressing the execution time in terms of the higher level primitive actions whose durations are represented symbolically and are called time-variables, such as the time to perform an addition or the overhead for a while loop. We then attempt to express the execution time of a program in terms of the time-variables and certain properties of the input (such as input size). We are particularly interested in studying the average case performance of programs.

The goals of this research are to develop mathematical techniques for analyzing the performance of programs executing on sequential and parallel machines and to design practical software tools for program analysis, based on these new techniques. An expected byproduct of this research is a new generation of software tools, which will help the programmer realize the promise offered by the exponential growth in the speed, size, and complexity of emerging parallel computer architectures.

Logic Programming

Logic programming is an evolving paradigm for computation based on mathematical logic. One of its goals is to develop very high level languages enabling the development of concise programs which have a greater likelihood of being correct or whose errors can be readily detected. One of the most recent developments in this field is Constraint Logic Programming (CLP) in which problems are stated by specifying the constraints that should be satisfied. The current research centers within the following areas:

1. parallel execution of logic and CLP programs;
2. partial evaluation and transformation of logic and CLP programs;
3. parallel algorithms for testing satisfiability of systems of constraints.

HARRY MAIRSON
Assistant Professor of
Computer Science

Logic and Types in Programming Languages

I am currently conducting research on the use of data types in programming languages, and its relationship between data types to classical ideas in mathematical logic. The philosophical roots of type theory are found in Russell and Whitehead's Principia Mathematica, with practical applications appearing in the design of programming languages and compilers. The problem of automatically inferring data types in "functional" programming languages have a strong connection with issues in mathematical logic. In particular, if every program Π has a type $\mathcal{T}$, then $\mathcal{T}$ can be thought of as a theorem and Π as a proof of that theorem. When many programs have the same type, it simply means that theorems can have more than one proof. This correspondence relates types to a kind of mathematics called constructive intuitionistic logic. I am working on understanding the computational complexity of theorem proving in various logics associated with respective typing systems.

Z. GEORGE MOU
Assistant Professor of
Computer Science

Programming Models and Languages For Massively Parallel Computations

Along with advance of VLSI technology, massively parallel computers with tens of thousands processors are available. Since these parallel computers have departed from the von Neumann machine model, much of our past experience with conventional computers cannot be used to guide the practice in the parallel world.

My current interest is to develop a parallel programming language called Divacon. This language is based on a formal model, which was proposed in my doctoral dissertation, for parallel computation by divide-and-conquer. Unlike many other parallel programming languages, Divacon is designed with the emphasis on choosing a small set of simple primitives with orthogonal properties and a small set of functional forms which can be used to construct complex functions from simple ones hierarchically. A preliminary version of the language has been embedded into the language *Lisp and runs on the Connection Machine. The programming experience in Divacon by a user group of moderate size has confirmed the language's potential strength in its expressiveness, modularity, and efficiency.

My current research projects include:

1. A formal definition of the language Divacon.

2. An initial version of a Divacon compiler for the Connection Machine.

3. A formal approach to reasoning about Divacon programs.

4. Automatic complexity analysis of Divacon programs.

5. Development of parallel algorithms in Divacon for scientific and engineering problems.

JAMES PUSTEJOVSKY
Assistant Professor of
Computer Science

Computational Models of Natural Language Semantics

There are two major goals I would like to accomplish with my current research. The first deals broadly with the semantics of natural language, and more specifically, with the nature of word meaning, compositionality, and the global organization of conceptual knowledge as shaped by language. The second aspect involves the verification and testing of these theories through computational models of representation of text and discourse.

The goal of computational linguistics is, in my opinion, the same as that of linguistics; to provide useful, testable, and, hopefully, explanatory theories of the nature of language and its relation to human cognition as a whole. Positioned at the center of the synthesis between these two fields is the study of word meaning, lexical semantics. Currently, I am working on specifying a general methodology and the specific formalism for expressing the semantic content of lexical items in natural language. Because a clear notion of semantic well-formedness is necessary in order to characterize a theory of possible word meaning, I abstract the notion of lexical meaning away from other semantic influences, such as world knowledge, discourse, and pragmatic factors.

Few existing semantic theories provide a method for the decomposition of lexical categories. What my research provides is a principled method of lexical decomposition, incorporating a rich, recursive theory of semantic composition, the notion of "semantic well-formedness," and a notion of how these representations are integrated into a larger knowledge representation language. Because there has been so little attention paid to other lexical categories besides verbs, my efforts have been centered on defining the minimal semantic representations for nouns and adjectives. Not until all major categories have been studied can we hope to arrive at a balanced understanding of the conceptual lexicon and the methods of composition.

My research suggests that lexical (and conceptual) decomposition is possible if it is performed generatively. Rather than assuming a fixed set of primitives, I assume a fixed number of generative devices that can be seen as constructing semantic expressions. For this reason, I think of a dictionary of concepts as a generative lexicon.

A grammar for lexical semantics is computationally interesting and useful only if the individual representations can be associated with nonlinguistic information, e.g. common-sense knowledge. My research will also focus on elaborating the semantic principles of lexical inheritance in the global lexicon. It is this level of semantics that gives us the integrated representation of the meaning of a sentence in a context.

JAMES A. STORER
Associate Professor of
Computer Science

Data Compression

In addition to continuing past work on lossless data compression (where the decompressed data must be identical to the original), a major lossy compression research effort is underway with funding from the NSF (decompressed data need only be an acceptable approximation to the original such as a digitized image that "looks" as good as the original). This effort includes both theoretical papers and experimental software. The goal is to investigate novel approaches to lossy compression and develop massively parallel algorithms capable of the high data rates needed for high definition video (over 1 billion bits per second). The recent successful design by Dr. Storer of a massively parallel custom VLSI chip for fully adaptive lossless compression at over 300 million bits per second has provided some of the impetus for this new research. Some of this work is in collaboration with M. Cohn and H. Mairson.

Communication Protocols

Most approaches to adaptive lossless or lossy data compression require a sender and receiver to maintain in a lock-step fashion constantly changing local data; that is, the receiver is constantly applying the same learning strategy used by the encoder to dynamically deduce the contents of the sender's local data. A single error on the communication line or storage device can corrupt all subsequent data. This research investigates a new low-overhead probabilistic technique for a "relaxed" form of error correction on what are essentially one-way channels (e.g., as satellite channels) where re-transmission of data is tantamount to losing the data that would otherwise have been transmitted.

Computational Geometry

This is a continuing effort to investigate motion planning problems from a theoretical standpoint.

Robotics

This is a new effort in collaboration with the AI researchers in the department. An experimental six-legged walking robot is close to completion that will be used to test practical motion planning, control, and learning algorithms.

DAVID WALTZ
Professor of Computer Science

Massively Parallel Artificial Intelligence

Professor Waltz specializes in artificial intelligence, with particular interest in massively parallel and "connectionist" models of computation. Connectionist (or "artificial neural net") models use large numbers of relatively simple, richly interconnected computational units to model cognitive phenomena. Professor Waltz has specifically investigated connectionist systems for learning, natural language processing, and classification problems. At the practical end of the spectrum, Professor Waltz has been investigating models for artificial intelligence that can run on new generation computers, such as the Connection Machine. While much of the earlier work in artificial intelligence was based on serial models (e.g. heuristic search), Professor Waltz believes that a new generation of AI applications can be built on the idea of global nearest match of an item in associative memory, a powerful but inexpensive operation on massively parallel machines. This class of methods, referred to as case-based or memory-based reasoning, has applications to tasks ranging from medical decision-making systems to software troubleshooting; Professor Waltz is engaged in specific projects covering document retrieval, automatic classification, and analysis of protein structure. Some of this research is being done in collaboration with Professors Alterman and Pustejovsky.

Professor Waltz's earlier research included the building of PLANES, an early natural language front end for database question answering; and the programming of a vision system for interpreting blocks world scenes, which introduced "constraint propagation", a method that has had widespread application in AI.

APPENDIX B3

RESEARCH ABSTRACTS

EXPERIMENTAL PSYCHOLOGY

EXPERIMENTAL PSYCHOLOGY

(Researchers: Halpern, Kramer,
Lackner, Morant, Sekuler, Todd,
Wingfield, Zurif)

The Experimental Psychology group within the Center faculty is composed of faculty members with varying specific interests. Their areas of research span a broad range of complex cognitive and perceptual functions that includes visual pattern perception, speech perception and production, memory and cognition, visual neurophysiology, human spatial orientation and motor control, and cognitive neuropsychology.

Dr. Lynn Halpern's research is in the area of binocular vision. Of special interest is how the brain matches features in the two eyes' views of the world to produce a single image in depth, and whether the neural mechanisms that detect the position in depth of visual targets also signals their motion in depth.

Dr. James Todd's research is concerned with how motion, texture and shading provide the visual system with useful information about the three-dimensional structure of the visual environment. Computer graphics are used to study such capabilities as the perception of solid shape from shading and the perception of structure from motion.

Dr. Arthur Wingfield's research focuses on human capability for the rapid perceptual processing of spoken natural language, and memory for its content. Studies of neurological populations and changes that occur in normal aging are used to shed light on sensory-cognitive interactions and compensatory operations.

Dr. Ricardo Morant's interests focus on visual perceptual adaptation, spatial orientation and the perception of spatial relationships. His research has also included the study of intersensory integration in infancy.

Dr. Steven Kramer's research interests are in perceptual and cognitive development. Currently, he is investigating how infants and young children use visual information, particularly motion information, to learn about their environments and to control their actions.

Dr. James Lackner's research interests concern human spatial orientation and motor control. His research program concentrates on adaptation to space flight and the etiology of space motion sickness.

LYNN HALPERN
Assistant Professor of
Physiological Psychology

How does the visual nervous system detect objects that move in depth?

An everyday task such as attempting to cross a busy street requires an individual to judge both fixed distances (such as that to the sidewalk on the other side of the street) and the direction and speed of motion of objects as they move through space (such as oncoming cars). My research program is concerned with how the visual nervous system allows us to detect such depth relations.

Different aspects of a visual scene, such as the color or shape of an object, how it moves or where it is located in depth, are analyzed independently by different groups of cells in the brain. The properties of these separate cell types can be characterized using behavioral techniques. Here, observers view visual targets that selectively stimulate activity in one group of cells (e.g., those that detect depth); observer responses reflect the ability of the visual cells to analyze information present in the visual target. These techniques are used not only to study how cells detect depth or motion, but also to learn how these two groups of cells interact to allow us to see objects that move in depth. That is, both the structure and function of visual cells in the brain are identified using noninvasive behavioral techniques.

This research has clinical applicability, since approximately 10% of the population is deficient in the ability to see depth. It also has human factors applications for design of equipment involving the use of visual displays.

STEVEN KRAMER
Assistant Professor of
Developmental Psychology

My research interests are primarily in the areas of perceptual and cognitive development. Currently, I am investigating how infants and young children use visual information (particularly motion) to learn about their environment and to control their actions.

Motion is an extremely rich source of information about the visual world. It provides information about the three-dimensional structure of objects, the relative distances and directions of objects and places, and about the organism's own movements with respect to the environment. In spite of its importance to the perceptual and cognitive development of the infant, little is known about the development of sensitivity to motion during the first years of life. My research has addressed this problem at a number of levels.

In order for an organism to use motion information, it must first be sensitive to image motion on the retina. My colleagues and I are assessing developmental changes in the visual system's sensitivity to the basic properties of motion (e.g., spatial and temporal displacement, and velocity). This research has demonstrated dramatic changes in infants' sensitivity to image motion, which have implications for perceptual and neural development within the visual system. The present research can be explained largely by development of the fovea during infancy. Planned research will investigate processes that are believed to be under cortical control.

It is not enough for the organism to be sensitive to motion in the image. It must also be able to use that information to learn about the world. Over the past several years, we have been studying infants' ability to use motion-carried information to extract the 3-dimensional structure of objects in their environment. This research has used point-light displays to show that infants as young as 3 months of age can extract at least some information about the three-dimensional form of a person based only on the relative motions of the point-lights. We have also found developmental changes in sensitivity to various sources of information (e.g., dynamic occlusion, local rigidity) in these displays. Planned research will look not only at the extraction of structure from motion, but infants' sensitivity to various classes of motion (e.g., different gait patterns).

Not only must the organism be sensitive to the perceptual information, it must also be able to use that information to control its actions in important ways. Optical flow (i.e., the global change in optical information resulting from self-movement) provides information about how an observer is moving relative to the environment. Adults are able to use this information to control their posture and maintain spatial orientation. We have found developmental changes in infants' ability to use optical flow to control their posture and to keep track of the relative locations of objects in the environment. Planned research will take a systems approach to examine the mutual influences of motor and visual development. For instance, recent evidence suggests that the onset of self-produced locomotion is causally related to aspects of perceptual development. However, the development of perceptual sensitivity may also lead to greater postural control which in turn may lead to further locomotor development.

JAMES R. LACKNER
Meshulam and Judith Riklis
Professor of Physiology

One of the primary concerns of our laboratory is understanding more about the way in which human movement control and orientation are calibrated to the 1G force environment of Earth. Information of this sort is critical in terms of understanding how humans will perform in non-terrestrial force environments such as in reduced gravity situations as on the moon or Mars, or in adapting to weightlessness itself as in orbital space flight. We are also concerned with how humans are able to adapt their sensory-motor control and locomotion to life in a rotating environment. The latter is especially critical with regard to developing techniques for using artificial gravity in long term space missions. Another one of our key concerns is understanding the etiology of space motion sickness so that we can develop prophylactic measures for preventing such sickness.

Our experiments are carried out under both ground-based as well as parabolic flight conditions. In parabolic flight we are able to study how the human body reacts to periods of weightlessness, 0G, and periods of high force. We have been studying how postural tonus is modulated by background force level in order to determine whether there are immediate changes in the reflex control of antigravity musculature of the body to compensate for variations in force level. We are also studying the control of eye and head movements under such altered gravitoinertial conditions to see if the normal synergy between movements of the head and the associated reflex movements of the eyes are altered by exposure to variations in G level.

Coupled with these experiments, we are looking at how the accuracy of eye/hand coordination is influenced by non-1G force levels. Part of this same set of experiments is to determine whether position sense of the limbs is affected as well as the apparent weight of the limbs by background force variations. These experiments are important from the standpoint of understanding the ways in which the control and appreciation of eye, head, and limb position are influenced by different background force levels.

We are also carrying out extensive studies on vestibular function in different force backgrounds. In these experiments, we are especially concerned to determine whether alterations in vestibular function are the sole factor in space motion sickness, or whether the altered weight and sensory-motor control of the head as a function of force level is also an important eliciting factor in space motion sickness.

In our ground-based experiments in the Graybiel Laboratory's slow rotation room, we are studying how subjects are able to adapt to a rotating environment. Of particular interest here is both the time course of adaptation as well as the specific nature of the adaptation that occurs and the persistence of the adaptation. The key feature of movement in a rotating environment is that movements out of the axis of rotation, that is non-parallel to the axis of rotation, elicit Coriolis forces which are linear forces proportional to the radial velocity of one's body movement and the rate of room rotation. Such forces are virtually absent in a stationary environment. The ability of humans to adapt to Coriolis forces is a key to our attempts to generate artificial gravity for long-term space missions.

We are also pursuing the possibility that an individual can maintain simultaneous adaptation to more than one force environment, for example, 1G and 0G, or to a rotating and non-rotating environment. Such adaptation would allow an individual to make transitions between the different force of rotational environments without disruption of performance. These studies will also contribute information useful for more fully understanding the nature of human sensory-motor adaptation to the 1G terrestrial environment in which life has evolved.

RICARDO B. MORANT
Professor of Psychology

Development of Intersensory Perception in Human Infancy

Adult perception is unitary, we see the texture which we feel and feel the form which we see. How sensory stimulation is integrated to produce such unified perception is the core problem of this research. This approach studies the effects of intersensory discordance on the behavior of young infants. Our paradigmistic experiment utilizes 60" parabolic mirrors to create realistic images of objects and then analyzes the responses as infants reach towards and through the images.

Human Spatial Orientation

This research program is designed to better understand man's ability to perceive spatial relationships and orient himself in space. Current interests include perceptual adaptation, sensory-motor interactions, motion perception and vestibular functions.

JAMES T. TODD
Professor of Psychology

Visual Space Perception

My research is concerned with how human observers use shading, texture and motion within two-dimensional visual images in order to perceive the structures of objects and events in three-dimensional space. By analyzing observers' responses to computer-generated visual displays, I attempt to create formal mathematical models of their underlying perceptual mechanisms. This research has important applications for designing intelligent machines that can control their own movements using visual information, and for improving the effectiveness of visual displays used in man-machine interactions.

ARTHUR WINGFIELD
Professor of Psychology

Human Cognitive Processes

This research centers on three related aspects of human cognitive processes: selective attention, speech perception and immediate memory. Studies of selective attention represent an attempt to determine the limits of one's capacity for handling simultaneous speech material, and theoretical models to account for such limitations. A special interest in this work is a better understanding of speech processing and memory ability in normal aging. Our work is thus conducted with elderly as well as young adults.

Neuropsychology

Analyses of performance decrements following focal brain damage can offer valuable insights into how the human brain is organized for higher mental functions. Of particular interest are specific word-finding difficulties commonly associated with aphasia. Results of experimental analyses of such difficulties could have important implications both for an understanding of systems of lexical access in general and possible mechanisms accounting for their disruption following focal brain lesions.

EDGAR ZURIF
Professor of Cognitive Science

Neurolinguistics

The general goal of this research is to advance our understanding of the manner in which language capacity is organized in the brain. This involves analyses of the comprehension limitations in the various forms of adult aphasia caused by focal brain damage, and in particular, it involves on-line analyses of the information processing systems that generate linguistic representations in real-time. Via these analyses, we seek to reconstruct aphasic disorders in terms of a cognitive architecture elaborated in real-time terms, and we position ourselves to evaluate the "biological feasibility" of linguistic theories -- i.e., to evaluate the extent to which the effects of brain damage on language can be aligned with the representational formats proposed in different linguistic theories. This work is based, in part, on a collaboration with Dr. Jane Grimshaw, Professor of Linguistics.

In a practical vein, the research yields information concerning reasonable forms of language remediation for aphasic patients.

APPENDIX B4

RESEARCH ABSTRACTS

LINGUISTICS AND COGNITIVE SCIENCE

JANE GRIMSHAW
Professor of Linguistics

Linguistic Theory and the Acquisition of Language

This research focuses on the interaction between linguistic theory, learnability theory and language acquisition. Of particular importance is a set of interrelated issues concerning conservative learning versus generalization, the absence of negative evidence and its consequences, and the interreaction of semantic and syntactic information. The goal is to develop a learnability model for linguistic rules and representations, and to explore its implications for language development.

Syntactic Theory and the Organization of the Mental Lexicon

The principles governing the mental representation of words are of central importance to theoretical linguistics. This research is a study of the lexicon, including such topics as the interaction of syntactic and semantic information in lexical entries, the definition of "lexical relatedness" and properties of lexical rules. The work has clear implications for psycholinguistic models of language processing and for models of the human language capacity such as those developed by artificial intelligence researchers.

RAY JACKENDOFF
Professor of Linguistics

Human Conceptual Structure

The research: My main research interest is in human conceptual structure, studied as a formal computational system. This is the system of organization in terms of which human thought is encoded, and it serves as the carrier of modality-independent information shared among all the sensory and motor systems and expressed in language.

The major focus of my research over the past fifteen years has been in the interface between conceptual structure and language, that is, the semantic system associated with language. I have succeeded in developing a theory of semantic primitives and principles of combination, Conceptual Semantics, in terms of which I have been able to work out a psychologically and linguistically responsible account of the semantics of large numbers of lexical items and syntactic constructions. Some of the general issues with which I have been particularly concerned are:

1. the formalization of prototypes, fuzzy categories, and family resemblance phenomena in lexical entries, using psychologically motivated systems of "preference rules";

2. the semantic relations among multiple syntactic frames of the same lexical item (especially verbs and prepositions);

3. semantic material in the meaning of a sentence that is contributed not by the lexical items but by syntactic constructions or by pragmatic "rules of construal";

4. formal parallels between the semantics of spatial concepts and that of other semantic fields such as possession, ascription, and time (the "Thematic Relations Hypothesis").

Areas I have worked on recently include:

1. argument structure of verbs and prepositions
2. the formalization of thematic roles (agent, patient, etc.)
3. distinctions between arguments and modifiers
4. causative constructions
5. resultative constructions
6. the mass-count distinction in nouns and its relation to aspectual (event-structure) distinctions in verb phrases.

Most of this material has been worked out with reference to English; however, preliminary work on various aspects of it, done by native speakers of other languages such as Spanish, Hungarian, Finnish, Italian, and Japanese suggest that it is a framework suitable for crosslinguistic investigation.

Potential application: One of the most difficult problems facing any computer implementation of natural language, whether for text comprehension, text generation, or automatic translation has been a robust characterization of the semantic underpinnings of the language. To the extent that my research has been successful in uncovering the psychological basis of human concepts and formalizing it in a reasonably rigorous fashion, one should be able to integrate the theory into such applications rather directly.

Spatial Cognition

The research: As an outgrowth of

my research on conceptual structure, it has become useful to investigate the question of how we can talk about what we see -- how information is translated from the visual system into a form accessible to linguistic expression. This is important for two reasons. First, language about space is very rich; and, because one can illustrate with pictures, it is especially easy to investigate as well. Second, many more abstract fields of concepts turn out to be built analogically on concepts of space, so that understanding of space provides a key to a much broader domain.

The issue I try to address in studying spatial cognition is what form of information the visual system provides at its upper end, sufficient to explain the ability of humans (and lower organisms) to perceive the world as stable and navigate through it. I take as a basis something like David Marr's 3D model or Irving Biederman's amplification of it. The additional kind of evidence I bring to the enterprise is linguistic, since spatial language must reflect the form in which the visual system delivers knowledge of space.

In work done in the middle 1980s, I showed that such a framework could be connected with conceptual structure, and that this connection solved nagging problems both in the theory of vision and in the theory of language. In more recent work done in collaboration with Barbara Landau, we have been able to flesh out some substance in the theory of spatial information, adding new kinds of primitives to the Marr-Biederman repertoire, and in particular showing how spatial relations among objects must be encoded, an issue largely unaddressed in perceptual theory.

Potential application: The theory of spatial understanding should be of importance to work in machine vision and robotics. The fact that a connection can now be made to linguistic expression makes it possible to envision as well a psychologically grounded linguistic interface with either of these enterprises.

JOAN MALING
Professor of Linguistics

Modern Icelandic Syntax

Icelandic is syntactically the most conservative of the modern Germanic languages (i.e., has changed the least in the last 1000 years). How is it different from, and how is it similar to, other Germanic languages? What light can the structure of Icelandic shed on syntactic change within Germanic? Research topics include the study of passive and middle voice, word formation rules, reflexive pronouns and word order (especially the Verb-Second Constraint).

Case-Marking and Grammatical Relations

Icelandic has the richest and most productive case-marking system of the modern Germanic languages. Hence it is ideal for investigating the mapping between morphological case and grammatical functions, and between these and thematic or semantic roles. How is Icelandic different from other Germanic languages? Research topics include case-preservation with respect to passive and middle voice and other word formation rules.

ALAN S. PRINCE
Professor of Linguistics
and Cognitive Science

Prosodic Phonology

Prosodic Structure. By imposing various conditions on grid and constituency structures, it is possible to develop optimal theories of stress and accent systems that rely mostly on descriptive apparatus drawn from general phonology, obtaining the chief domain-specific properties of such systems as formal consequences.

Non-concatenative morphology. Template form in re-duplication, hypocoristics, language games, and Semitic-like root/pattern systems is determined entirely within the vocabulary of suprasegmental prosodic categories. (With John McCarthy, Bell Labs and UMass-Amherst.)

MOIRA YIP
Assistant Professor of
Cognitive Science

The Organization and Specification of Phonological Features

The sound system of languages shows a hierarchical organization at all levels. Distinctive features are universally grouped into sets, which in turn are grouped into more inclusive sets, until the full set constitutes the phoneme. Phonemes are in turn grouped into prosodic constituents such as syllables and stress feet. My current research investigates how this system manifests itself in Chinese languages (Mandarin, Cantonese, and others) (see Yip 1989, 1990, 1991). These languages offer the native speaker little surface evidence that would allow them to discern the hierarchical properties of the system, and yet at a deeper level we discover crucial reference to featural subsets such as Laryngeal and prosodic groupings such as stress foot. For example, Cantonese, a language with no stress, uses the bisyllabic foot as a template in forming names, so that monosyllabic inputs are extended with a "filler syllable". The rare bisyllabic inputs, however, lack such an extension (Yip 1991). This line of research suggests that the hierarchical organization must be part of the intrinsic organization of the language capacity, and thus unlearnt, since it would seem in Chinese to be unlearnable.

In addition to having hierarchical representations, languages have been found to observe certain universal well-formedness principles defined on those representations. Forms arising in the course of linguistic composition that would violate these principles must be changed so as to conform to them. Yip (1987) shows that an appropriately generalized version of the Obligatory Contour Principle (O.C.P.), which disallows identical adjacent elements in representations, and is known to constrain the shape of underlying forms and block the operation of phonological rules, can also force the operation of rules in the direction of well-formedness. Schematically, an O.C.P.-violating input sequence /tt/, which can arise due to concatenation of morphemes, must undergo mutation to become well-formed: it will either dissimilate, e.g. to /tp/, simplify to /t/, or acquire a vowel, becoming /tat/. Cases from a wide range of languages and phonological phenomena support this view, which has important consequences for our understanding of the way general principles operate in the grammars of individual languages. Such powerful universal principles play an important role in the task of language acquisition, since they determine the character of the rule-system that the child learner induces from linguistic experience.

APPENDIX C

ONGOING CENTER ACTIVITIES

CENTER ACTIVITIES

1988/89 Lecture Series:

- Dr. David Tank from Bell Laboratories spoke about lessons to be learned from computer models of neural circuits.

- Professor Paul Adams from the State University of New York at Stony Brook discussed the role of calcium in the integration of signals and intracellular computation in nerve cells.

- Professor Paul Smolensky from the University of Colorado at Boulder described models of the structure and representation of knowledge in neural networks.

1989/90 Lecture Series:

- Professor Richard Anderson from MIT spoke on "Cortical Neurons, Spatial Perception and Neural Networks."

- Professor Nancy Kopell from Boston University spoke on "Structure and Function in an Oscillatory Neural Network."

- Professor Leon Glass from McGill University discussed "Complex Rhythms in Biological Systems."

- Professor Scott Kelso from Florida Atlantic University spoke on "Phase Attraction: An Ordering Principle for Cooperative Behavior in Complex Systems."

- Professor Geoffrey Hinton from the University of Toronto discussed "Spatial Coherence as an Internal Teacher for a Neural Network."

- Professor Anatol Zhabotinsky of the National Institute for Hematology in Moscow discussed "Chemical Oscillations and Waves: History and Problems."

1990/91 Lecture Series:

- Dr. John Rinzel from the National Institutes of Health spoke on "Rhythmic Behavior of the Pancreas: Insights from Theoretical Models."

- Professor Albert J. Libchaber from the James Franck Institute at the University of Chicago spoke on "Thermal Turbulence."

- Professor Irving Biederman from the University of Minnesota discussed "How an Account of Perceptual Organization, Shape Recognition, and Visual Attention Can Emerge From a Neural Network that Solves the Binding Problem."

1990/91 Lecture Series, continued:

- Dr. Jonathan Winson from Rockefeller University spoke on "The Function of REM Sleep and the Meaning of Dreams."
- Dr. Apostolos Georgopoulos from Johns Hopkins University School of Medicine spoke on "Psychophysical and Neural Studies of Motor Cognitive Functions."

SCIENTIFIC RETREAT
SACHAR INTERNATIONAL CENTER
THURSDAY, MAY 25, 1989

9:00 A.M.	REGISTRATION AND COFFEE
9:30	WELCOME: EVELYN E. HANDLER, PRESIDENT; IRWIN B. LEVITAN, PROFESSOR OF BIOCHEMISTRY
9:45	"A COMPUTATIONAL MODEL FOR WORD MEANING IN NATURAL LANGUAGE" JAMES PUSTEJOVSKY, ASSISTANT PROFESSOR OF COMPUTER SCIENCE
10:30	"LANGUAGE AND BRAIN" EDGAR ZURIF, PROFESSOR OF COGNITIVE SCIENCE
11:15	BREAK
11:30	"CHANNELS IN THE VISUAL NERVOUS SYSTEM FOR DETECTING MOTION IN DEPTH" LYNN HALPERN, ASSISTANT PROFESSOR OF PHYSIOLOGICAL PSYCHOLOGY
12:15 P.M.	LUNCH
1:30	"OSCILLATORY BEHAVIOR IN TIME AND SPACE" IRVING R. EPSTEIN, PROFESSOR OF CHEMISTRY
2:15	"MATHEMATICAL MODELLING OF NEURAL NETWORKS" LAURENCE F. ABBOTT, PROFESSOR OF PHYSICS
3:00	BREAK
3:15	"HOW A BIOLOGICAL NEURAL NETWORK GENERATES BEHAVIOR" EVE E. MARDER, ASSOCIATE PROFESSOR OF BIOLOGY
4:00	POSTER SESSION AND REFRESHMENTS
5:30	BARBECUE

SCIENTIFIC RETREAT
"LEARNING AND MEMORY"
SACHAR INTERNATIONAL CENTER
THURSDAY, JUNE 14, 1990

9:00 A.M.	REGISTRATION AND COFFEE
9:30	WELCOME: IRWIN B. LEVITAN, PROFESSOR OF BIOCHEMISTRY AND DIRECTOR, CENTER FOR COMPLEX SYSTEMS
9:45	"ASSOCIATIVE MEMORY AND LEARNING: MODELS AND APPLICATIONS" DAVID WALTZ, PROFESSOR OF COMPUTER SCIENCE
10:30	"SELF ORGANIZING NEURAL NETWORKS FOR LEARNING AND MEMORY OF COGNITIVE RECOGNITION CODES" GAIL CARPENTER, CENTER FOR ADAPTIVE SYSTEMS, BOSTON UNIVERSITY
11:15	BREAK
11:30	"HOW TO LEARN A LANGUAGE" JANE GRIMSHAW, ASSOCIATE PROFESSOR OF LINGUISTICS AND COGNITIVE SCIENCE
12:15 P.M.	LUNCH
1:30	"LANGUAGE, MEMORY, AND AGE: AN EXPERT SYSTEM IN NATURE" ARTHUR WINGFIELD, PROFESSOR OF PSYCHOLOGY
2:15	"IN SEARCH OF GENES INVOLVED WITH LEARNING AND MEMORY IN FRUIT FLIES" TIM TULLY, ASSISTANT PROFESSOR OF BIOLOGY
3:00	BREAK
3:15	"MEMORIES ARE MADE OF THIS; A MODEL OF THE MOLECULAR BASIS OF MEMORY" JOHN LISMAN, PROFESSOR OF BIOLOGY
4:00	POSTER SESSION AND REFRESHMENTS

Center for
Complex Systems

Brandeis University

CCS Report

Cognitive Science Neuroscience Computer Science

THE CENTER FOR COMPLEX SYSTEMS: A PROGRESS REPORT

Irwin B. Levitan, Center Director

The Center for Complex Systems, Brandeis' interdisciplinary enterprise in the cognitive, neural and computational sciences, is in its second year of operation. In this article Center Director Irwin B. Levitan, Professor of Biochemistry, discusses the goals of the Center and its role in the Brandeis community.

THE SCIENCES AT BRANDEIS

It is impossible to discuss the Center for Complex Systems without placing it in the framework of Brandeis' overall effort in science. The university has for most of its existence been distinguished for its excellence in basic research and graduate training in the sciences. In spite of the relatively small size of its science faculty, Brandeis boasts eight members of the National Academy of Sciences and twenty-three members of the American Academy of Arts and Sciences. Many of the science faculty have received special research awards from the National Science Foundation and the National Institutes of Health, as well as from private foundations, and two members of the biomedical science faculty are Howard Hughes Medical Institute Investigators. External research support generated by the science faculty contributes substantially to the University's total operating budget, and national studies rank the scholarly competence and achievements of Brandeis science faculty at the very highest level.

THE CENTER FOR COMPLEX SYSTEMS

This background of distinguished achievement provides the context for Brandeis' most recent initiative to develop the Center for Complex Systems. The

(continued on page 2)

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Center has been under discussion on campus since the end of 1986, and was formally established in July of 1989. The purpose of the Center is to advance the study of the brain and intelligence using a broad array of techniques and approaches. It brings together investigators with backgrounds in computer science, cognitive science and linguistics, neuroscience and experimental psychology, in an effort to understand that most complex of systems, the brain, and the way the brain controls behavior. These investigators have to date been drawn from six different Brandeis departments: Psychology, Computer Science, Biology, Biochemistry, Chemistry and Physics. Thus the Center is a truly interdisciplinary entity which unites an astonishingly diverse group of faculty in a common goal. We are excited by the breadth of this endeavour - it is unprecedented.

NOVEL EDUCATIONAL OPPORTUNITIES

In its short existence the Center has already fostered a series of initiatives in both graduate and undergraduate education. Although there has been no need thus far to introduce new degree-granting graduate programs, Center faculty are providing a unique interdisciplinary training environment for graduate students and postdoctoral fellows. These students emerge from their training free of the constraints imposed by traditional disciplinary boundaries, and are poised to make novel research contributions on the forefront of studies of the brain and intelligence. In addition a new undergraduate concentration in neuroscience has been established under the Center umbrella. The broad-based interdepartmental program is appropriate for premedical students or for those who wish to go on to any one of a number of graduate programs, and students who complete this concentration will be conspicuous for their diversity. Although it is only in its first year, it is gratifying to see the numbers and particularly the quality of the Brandeis undergraduates who are choosing to major in neuroscience. As an important part of Brandeis' overall effort to provide a rich educational environment, the neuroscience concentration will contribute to attracting the very best undergraduates to the university.

INTERDISCIPLINARY RESEARCH

As noted above Brandeis is home to numerous distinguished scholars and teachers. The Center for Complex Systems has been fortunate in being able to draw its members from so notable a group of faculty. It provides them with a novel context in which to do research, an environment in which they can interact with other scientists with diverse backgrounds but who share a common goal. This environment has already spawned unique research projects which would barely have been imaginable without the Center umbrella. For example, linguists from the Psychology Department are collaborating with members of the Computer Science Department to model the way in which the brain processes language. Another project has faculty and students from the Biology, Chemistry and Physics Departments working together on computer models of interactions among nerve cells in neural circuits which control behaviors. This project has recently been funded by a $1,000,000 grant from the National Institute of Mental Health; if such an award to three principal investigators from three different academic departments is not unique, it certainly is rare. The results of studies such as these will be of importance to a variety of fields. On the one hand they will of course advance our understanding of how the brain works; at the same time better understanding of the biological systems will contribute to the design of faster and more powerful computer systems, another major goal of the Center. Even without formal collaborations such as those described here, proximity and informal interactions alone will profoundly influence the research directions of Center members. There is a synergy resulting simply from the proximity of scientists with diverse perspectives and approaches to a problem, a synergy with important consequences for fundamental research.

A HOME FOR THE CENTER

The importance of proximity dictates the need for a central facility to house Center faculty and students if the Center is to develop its full potential. This requirement, together with the long-standing need for new space for the Computer Science Department, led the University to seek federal funds for a new science building. A $3,000,000 grant several years ago from the Department of Energy for planning and architectural studies was supplemented in November, 1990 by a $4,000,000 award for new construction from the General Services Administration. With good prospects for further federal funding in 1991, planning for the new complex is going ahead with the intention of beginning the first phase of construction early in 1992. Ultimately the overall building project will include renovation and expansion of the Gerstenzang Science Library and new Physics laboratories, as well as additional research space for the Center facility. The Center building itself will serve several important purposes for the University. For example it will provide a sorely-needed home for the entire Computer Science Department, and will relieve some of the serious space constraints in the present science complex. From the point of view of the Center, it will provide a central administrative, teaching and research facility in which Center faculty and students can interact in formal and informal ways.

THE CENTER AND BRANDEIS

The Center contributes in important ways to the Brandeis community by providing innovative directions in research and education. Furthermore, it has already generated and surely will continue to generate new research funding, which in turn contributes not-insubstantial new income to the University's general operating budget in the form of indirect cost recovery. The Center has done this by taking talented Brandeis faculty with overlapping interests and providing them with an opportunity to interact. It is one of the newest and perhaps the broadest of such programs at Brandeis, but it is not the only one. Other excellent interdisciplinary groups on campus also provide a rich educational and research environment, and surely more of these will form and flourish in the future. We are excited by the opportunities for Brandeis as a whole that such new associations afford.

THE CENTER FOR COMPLEX SYSTEMS

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CCS News Briefs ...

CCS RETREAT A SUCCESS

The second annual CCS retreat was held on June 14th, 1990 in the Sachar building on campus. The theme was "Learning and Memory." The day was a success, featuring six fine lectures, a diverse and educational poster session, and an enjoyable social atmosphere.

The lectures given were:

1. "Associative Memory and Learning: Models and Applications" ; David Waltz, Professor of Computer Science;
2. "Self Organizing Neural Networks for Learning and Memory of Cognitive Recognition Codes"; Gail Carpenter, Center for Adaptive Systems, Boston University;
3. "How to Learn a Language"; Jane Grimshaw, Professor of Linguistics and Cognitive Science;
4. "Language, Memory, and Age: An Expert System in Nature"; Arthur Wingfield, Professor of Psychology;
5. "In Search of Genes Involved with Learning and Memory in Fruit Flies"; Tim Tully, Assistant Professor of Biology; and
6. "Memories Are Made of This; A Model of the Molecular Basis of Memory"; John Lisman, Professor of Biology.

Plans are now being made for the 1991 retreat, which will be held on June 4th in the Sachar building. This year's theme will be "Vision." Confirmed speakers are Provost Robert Sekuler, and Professors James Todd, John Lisman, and Daniel Oprian. There will also be several outside speakers.

CCS RESEARCH: NSF GRANT

The National Science Foundation has awarded a research grant to two Center faculty members. Professors Irving Epstein (Chemistry) and Eve Marder (Biology) have received a grant for their work on chemical and neural coupled networks. As stated in their proposal; "By studying some relatively complex chemical reactions and a relatively simple neural network, we hope to derive new insights into how the different parts of a network interact to produce rhythmic behavior. Ultimately, we seek to explain how groups of neurons work together to generate and modulate simple rhythmic behaviors such as walking, chewing, or breathing."

RESEARCH PUBLISHED

An article submitted under the heading of the Center For Complex Systems was published in the April 6, 1990 issue of Science. The article was written by Thomas B. Kepler, Eve Marder, and L.F. Abbott, and was titled "The Effect of Electrical Coupling on the Frequency of Model Neuronal Oscillators." This article is the first to be published using the Center For Complex Systems name.

"Neurons with oscillatory properties are a common feature of the nervous system, but little is known about how neural oscillators shape the behavior of neuronal networks or how network interactions influence the properties of neural oscillators. Mathematical models are used to examine the effect of electrically coupling an oscillatory neuron to a second neuron that is either silent or tonically firing. Models of oscillatory neurons with varying degrees of complexity show that this coupling can either increase or decrease the frequency of an oscillator, depending on its membrane potential wave form, the state of the neuron to which it is coupled, and the strength of the coupling. Thus, electrical coupling provides a flexible mechanism for modifying the behavior of an oscillatory neural network." (Abstract from Science 248, p. 83, 1990)

NEUROSCIENCE MAJOR

The new concentration in 'Neuroscience' became available to students in the fall 1990 semester. More than 25 students have declared Neuroscience as their primary area of concentration. This major encourages students to study the brain and its functions from many points of view. Students will establish strong foundations in basic science, and will be exposed to recent advances in neurobiology, neural networks, neuropsychology and experimental psychology.

LECTURE SERIES

The 1990-91 Center For Complex Systems lecture series is sponsoring five speakers. The speakers this fall were:

1. John Rinzel, from the National Institutes of Health, who spoke on "Rhythmic Behavior of the Pancreas: Insights from Theoretical Models."
2. Albert J. Libchaber, from the James Franck Institute at the University of Chicago, who spoke on "Thermal Turbulence." This lecture was cosponsored by the Physics Department and the Martin Weiner lecture series.
3. Irving Biederman, from the University of Minnesota, who discussed "How an Account of Perceptual Organization, Shape Recognition, and Visual Attention Can Emerge From a Neural Network that Solves the Binding Problem."

The two speakers scheduled for the spring semester are: 1) Professor Jonathan Winson from the department of Physiology and Psychology at Rockefeller University, on March 14th, and 2) Professor of Neurophysiology Apostolos Georgopoulos, from the Johns Hopkins University, on April 4th.

FEDERAL GRANT RECEIVED FOR CCS BUILDING

The Center For Complex Systems has been awarded a $4 million construction grant from the Federal Government. President George Bush signed the appropriations bill in November, which included funding for construction and renovations projects across the nation.

This $4 million makes a significant contribution to the first phase of construction, which will contain the main research component of the Center. Construction is slated to begin in 1992.

The project is currently in the design/development phase, with plans to begin construction documents this spring.

THE CONSORTIUM FOR THE CENTER FOR COMPLEX SYSTEMS

The Center for Complex Systems is seeking ways to interact more closely with scientists in industry. As the first major step in that direction, a consortium of companies interested in research work of faculty members is being considered. Although still in its formative stages, the Consortium is expected to consist of both U.S. and foreign companies who will obtain a first hand view of the Center's world class, leading edge technology.

Biotechnology, pharmaceutical, computer software and hardware companies, as well as those companies interested in learning, language and information storage, retrieval and transmission, and visual and other sensory perceptions are all potential Consortium members.

It is expected that the initial relationships developed between Consortium members and Center faculty will lead to both collaborative research projects with individual companies and an increased overall public awareness of Brandeis' powerful scientific capabilities.

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